



Directions in Engine-Efficiency and Emissions Research (DEER) Conference 3 October 2011



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What We Do

- **Acquisition:** Program Management
- **Logistics:** Industrial Operations, and Contracting
- **Technology:** Research, Development, and Life Cycle Engineering

The Magnitude

- Over 60% of the Army's Equipment and Systems (65% BCT's)
- Over 130 Allied Countries Own Our Equipment
- Approximately 3,300 Fielded Product Lines and 38,500 Components

The Product Lines

- | | |
|---|---------------------------------|
| 1. Mine Resistant Ambush Protected (MRAP) | 14. Force Providers |
| 2. Combat Vehicles | 15. Materiel Handling Equipment |
| 3. Armored Security Vehicle | 16. Chemical Defense Equipment |
| 4. Route Clearing Vehicle | 17. Tactical Bridges |
| 5. Howitzers | 18. Fuel & Water Dist Equipment |
| 6. Tactical Vehicles | 19. Trailers |
| 7. Rifles / Machine Guns | 20. Watercraft |
| 8. Large Caliber Guns | 21. Rail |
| 9. Mortars | 22. Construction Equipment |
| 10. Rapid Fielding Initiative | 23. Commercial Vehicles |
| 11. Aircraft Armaments | 24. Fuel & Lubricant Containers |
| 12. Robotics | 25. Sets, Kits & Outfits |
| 13. Soldier Uniforms & Equipment | 26. Shop Equipment |



We support a diverse set of product lines through their life cycles, from combat and tactical vehicles, armaments, watercraft, fuel and water distribution equipment, to soldier, biological, and chemical equipment.

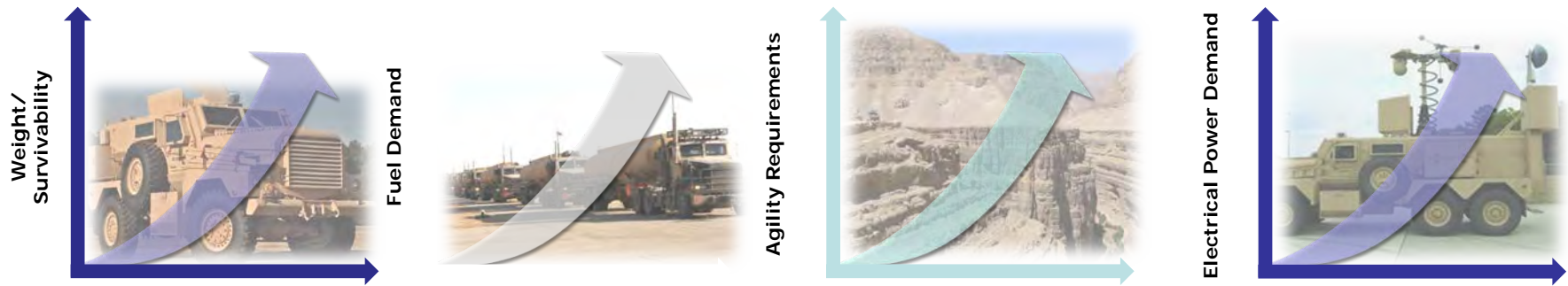
► Tactical Vehicles

Vehicle	Description	Units
Light Tactical Vehicles (LTV)	HMMWV vehicle variants made up of 1 ¼ ton payload class	163,661
Medium Tactical Vehicles (MTV)	14 variants in 2.5 and 5 ton payload class	43,143
Heavy Tactical Vehicles (HTV)	Heavy-duty trucks, 10 ton and up, used for cargo, moving heavy equipment, tractors, tankers, wreckers, fire fighting trucks, dump trucks and others	55,236
Mine Resistant Ambush Protected (MRAP)	A family of armored fighting vehicles designed to survive IED attacks and ambushes	10,902 (*16238 required)
Total		272,942

► Non-Tactical Vehicles

Vehicle	Description	Units
Passenger Vehicles	Sedans, station wagons, passenger vans, SUVs	86,138
Light Trucks	Vans, pickup trucks	42,665
Medium Trucks	Miscellaneous cargo, flatbed, boxvan, others	43,762
Trucks	Heavy-duty trucks	17,598
Other	Ambulances, buses and support vehicles	6,633
Total		196,796

- All tactical vehicles are considered medium or heavy-duty by commercial standards (they are above 10,000 GVW, and all use JP8)
- About 30 percent of non-tactical vehicles are also medium or heavy-duty
- In total, about 72% of the total DoD fleet is medium or heavy-duty vehicles



Increasing demands, operational flexibility, and inter-relationships
Requires a Systems Engineering approach and investments in key technology areas



Powertrain



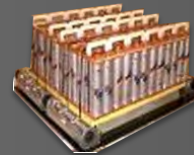
Thermal
Management



Track &
Suspension



Non-Prime
Power



Energy
Storage



Pulse
Power



Advanced
Propulsion

Systems Level Analysis, Integration and Testing

Power, Energy & Mobility



Newton-Euler Equations of Motion

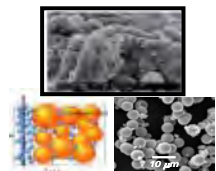
$$\left. \begin{aligned} M\ddot{q} + C_q^T \lambda &= Q \\ C(q, t) &= 0 \end{aligned} \right\}$$

Solve for vehicle mobility and component loads

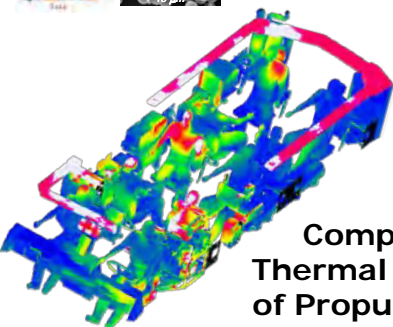
$$\begin{bmatrix} M & C_q^T \\ C_q & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ \lambda \end{bmatrix} = \begin{bmatrix} Q_c + Q_r \\ Q_d \end{bmatrix}$$

Vehicle Dynamics

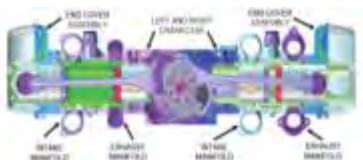
Hi-Energy, Hi-Density Energy Storage



Comprehensive Thermal Management of Propulsion & Cabin



High Power Density, Low Heat Rejection & Fuel Efficient Engines



Soldier & System Survivability



Active Protection Systems



Holistic Occupant Centric Protection

$$\frac{d}{dt} \int_{V_t} f(x, t) dV = \int_{V_c=V_t} \frac{\partial f(x, t)}{\partial t} dV + \int_{S_c=S_t} f(x, t) \cdot n dS$$

Affordable, Multi-hit Ceramic Armor



$$\frac{dc}{dt} + i\omega(p)c + \Gamma_+(p)c - \Gamma_-(p)c = f_n(t)$$

Fire and Toxic Fume Resistant Materials



Multi-Physics Optimization

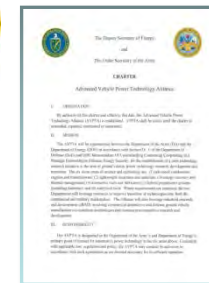
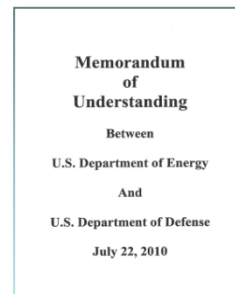
It's About Balancing Technology, Integration, Mission & Threat



AVPTA will move us toward reducing our reliance on fossil fuels.

Combines the intellect of the DA and the DOE to accelerate energy-related R&D initiatives.

Advanced Vehicle Power Technology Alliance (AVPTA) Breaking New Ground



22 July, 2010

18 July, 2011

- Partnership with true collaboration to enhance national energy security
- Demonstrate federal government leadership
- Provide shared capabilities and access to resources
- Accelerate technology development
- Drive innovation
- Increase the value of research investments
- Address national energy needs

Advanced Combustion Engines and Transmissions	Lightweight Structures and Materials	Energy Recovery and Thermal Management	Alternative Fuels and Lubricants	Hybrid Power Systems	Analytical Tools
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Technical areas for potential joint activity:

<ul style="list-style-type: none"> • High density, energy efficient powertrain • Extreme gains in engine efficiency <p>❖ Spray Visualization Project</p>	<ul style="list-style-type: none"> • Reduce weight to improve performance • Cost reduction for consumer market <p>❖ Carbon Fiber Project</p>	<ul style="list-style-type: none"> • Cost Improved efficiency, manage heat generation • Efficiency gains through waste heat recovery <p>❖ Thermoelectrics and Enabling Engine Project</p>	<ul style="list-style-type: none"> • Standardization & security • Efficiency gains through advanced oil formulations 	<ul style="list-style-type: none"> • Efficiency improvements <p>❖ CAEBAT Project</p> <p>❖ Permanent Magnetic Project</p>	<ul style="list-style-type: none"> • Assessment/ Design Trades
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Driving results through collaboration

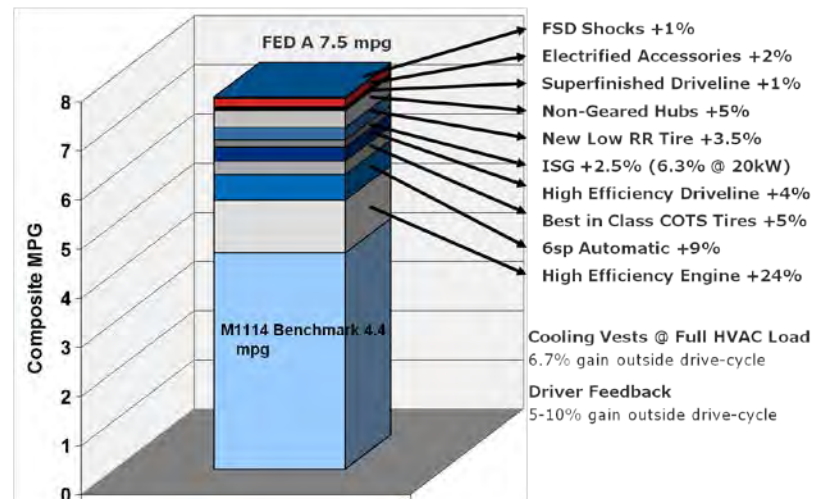
FED FUEL EFFICIENT GROUND VEHICLE DEMONSTRATOR



Designed to validate fuel-efficiency innovations, enhance Soldier safety and reduce Army's energy costs.

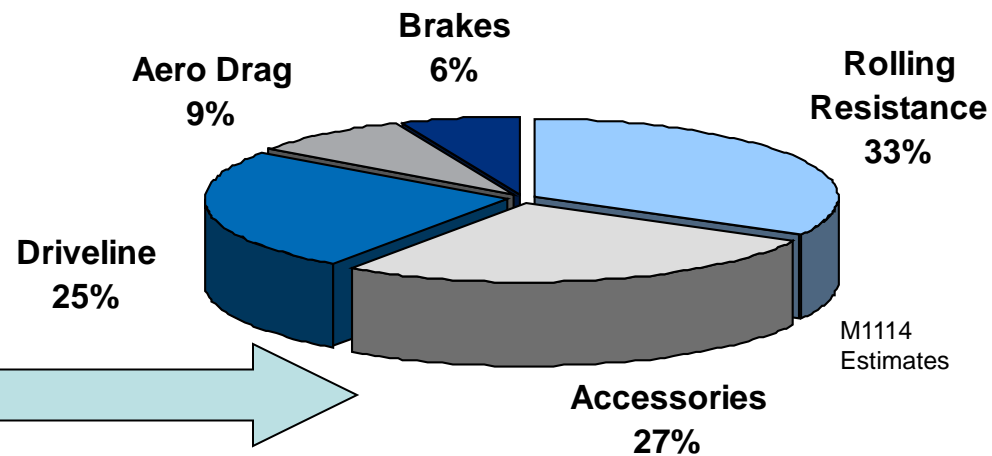
System engineering approach.
Exceeded the original goal of 30% more fuel efficient than the M1114

Fuel Efficiency Demonstrator (FED) OSD Sponsored, Army Implemented



- Identify and assess technologies that support increasing fuel efficiency in a M1114 size vehicle and demonstrate them in a system level demonstrator
 - Alpha – Testing began July 2011
 - Bravo – Nov 2011 delivery
- Developed detailed models & simulations to evaluate energy generation, losses, recovery, etc.
- Engine Energy & Vehicle energy analysis and balancing

Vehicle Energy Balance



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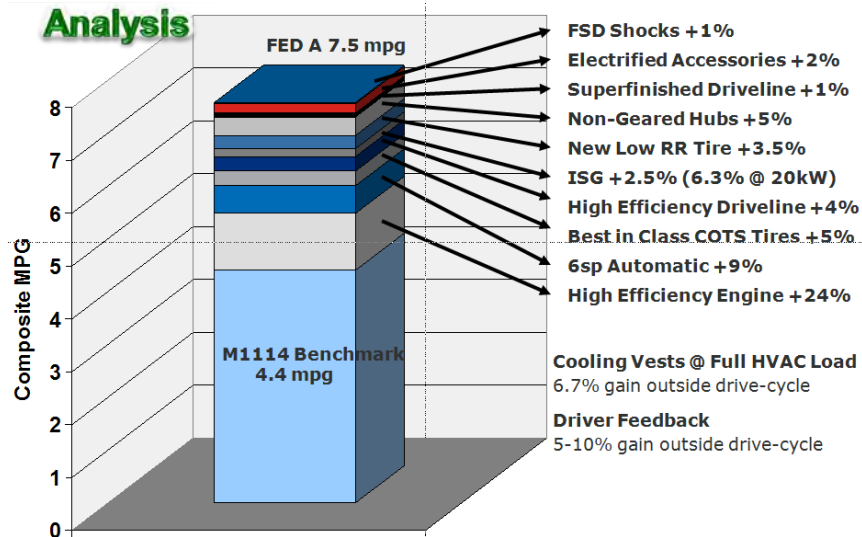
graph LR
    FED((FED)) --> DB(Driver Behavior)
    FED --> EP(External Power)
    FED --> ER(Energy Recovery)
    FED --> PG(Power Generation)
    FED --> PL(Parasitic Losses)
    
    ER --> EHR((+ Exhaust Heat Recovery))
    EHR --> EHR1[High Efficiency Battery Technology]
    EHR --> EHR2[Turbo-Compounding Electric]
    EHR --> EHR3[Turbo-Compounding Mechanical]
    EHR --> EHR4[Thermo-Electrics]
    EHR --> EHR5[Rankine Cycle]
    EHR --> EHR6[Stirling Engines]
    EHR --> EHR7[Fuel Reformers]
    
    ER --> CHR((+ Cooling Heat Recovery))
    ER --> RB((+ Regenerative Braking))
    ER --> RD[Regenerative Damping]
  
```

Efficiency Measures

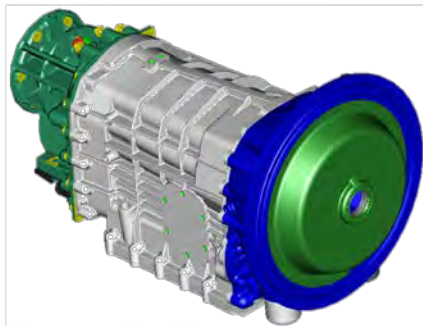
- Driver Behavior** (+)
- External Power** (+)
- Energy Recovery** (-)
 - High Efficiency Battery Technology (+)
 - Turbo-Compounding Electric
 - Turbo-Compounding Mechanical
 - Thermo-Electrics
 - Rankine Cycle
 - Stirling Engines
 - Fuel Reformers
 - Cooling Heat Recovery (+)
 - Regenerative Braking (+)
 - Regenerative Damping
- Power Generation** (+)
- Parasitic Losses** (+)

Fuel Efficient Demonstrator (FED)

Analysis

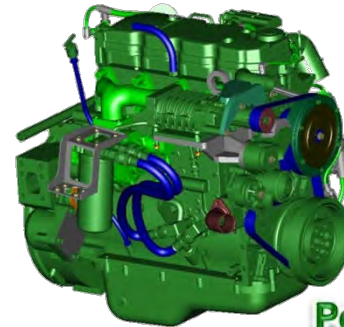


Greatest single contributor to upgrade efficiency is 7-speed dual clutch transmission, best non-hybrid efficiency option.



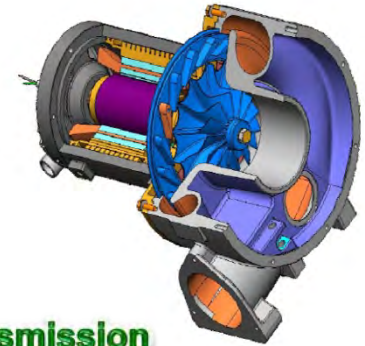
Power Transmission

200hp 4.5L I4 diesel; Calibrated for max efficiency.
Right-sized for application



Power Transmission

Electric Turbo-Compounding utilizes wasted heat energy.



35% rolling resistance improvement (pavement) using 22.5" commercial wheel w/ custom tread & tire compound.



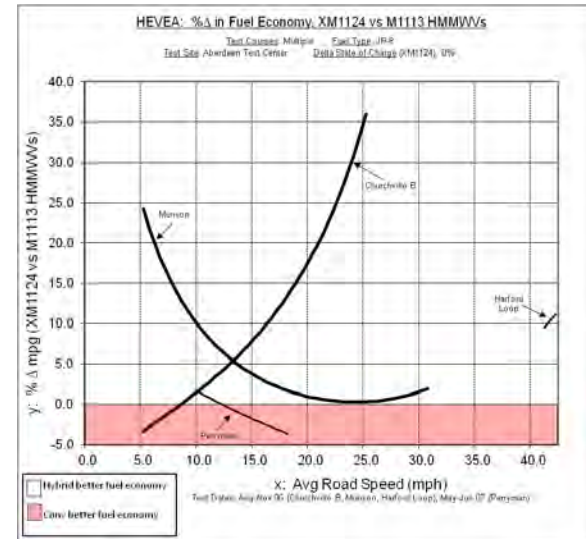
Materials



HEVEA - In 4 years, the Army developed physical & analytical methods for evaluating conventional and hybrid vehicles which have been accepted by the acquisition and industry communities, including SAE.

Hybrid Electric Vehicle Experimentation and Assessment (HEVEA)

20 Vehicles (10 Conventional/10 Hybrid)



- Developed a standard testing procedure & methodology for testing HEV's
- Developed analytical tools for both assessment and evaluation
- Established credible/quantifiable data of HEV vice conventional vehicles (fuel economy, reliability,
- Developed M&S methods

Accomplishments

- **Developed analytical tools for both assessment and evaluation**
 - Implemented as a design tool for the JLTV effort
 - Used on FED program
 - Sensitivity analysis of data ongoing

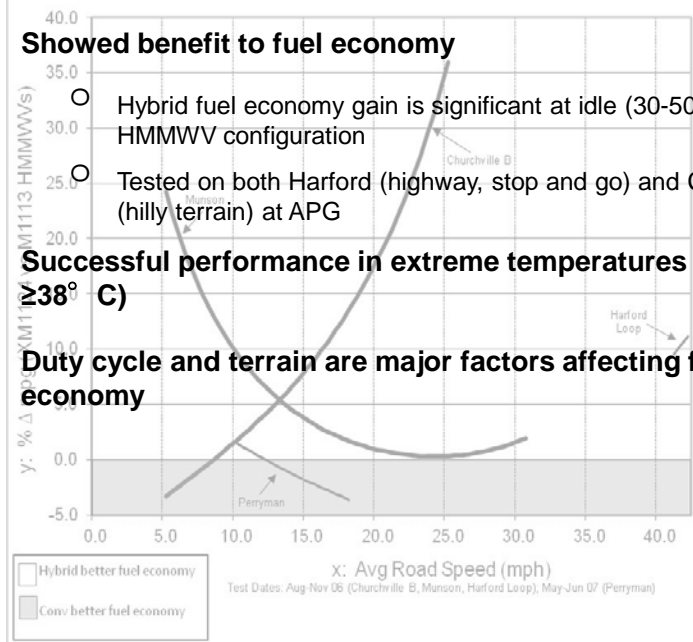
- **Developed physical test for hybrid electric systems - the TOP**

Shown benefit to fuel economy

- Hybrid fuel economy gain is significant at idle (30-50%) for test HMMWV configuration
- Tested on both Harford (highway, stop and go) and Churchillville (hilly terrain) at APG

- **Successful performance in extreme temperatures (-32° to ≥38° C)**

- **Duty cycle and terrain are major factors affecting fuel economy**



Hybrid-Electric Work to do


- **Reliability** – Evaluate the reliability of technology in military environment
- **Operational Analysis** – Assess technology value in operational scenarios
- **Cost Analysis** – Conduct cost analysis of fuel savings versus cost incurred for a specific platform in an operational mode
- **Life Cycle Cost Analysis** - Evaluate life cycle costs

Hybrid Electric Advantages

- Hybrid electric provides additional mission capabilities:
 - Power Generation – (On-board vehicle power)
 - Auxiliary Engine Support
 - Export Power
 - Silent operations



Marine Corps Base Hawaii (MCBH)



Hickam AFB

Hawaii's Energy from Oil

90%

HI Imports 51 million barrels of Oil Annually

\$7B

Hawaii's Supply of Oil (at any given time)

14-21 Days

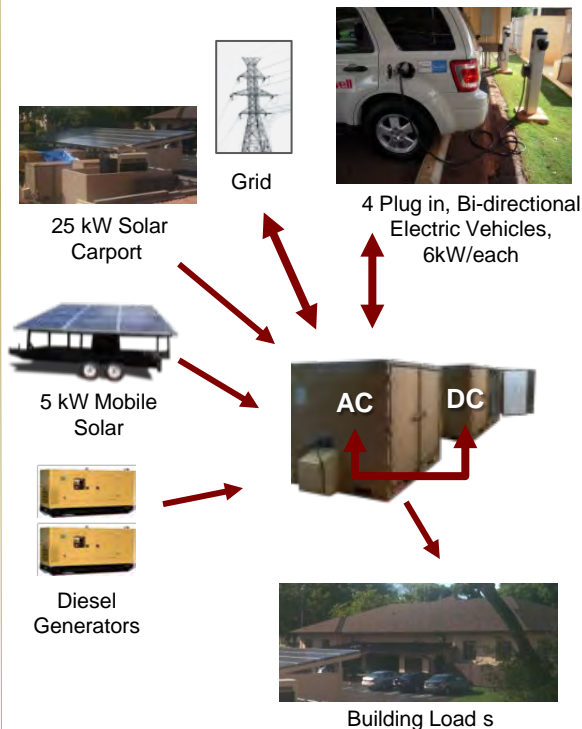
- Hawaii Tri-Service Advanced Vehicle Working Group
- DOD-DOE Advanced Vehicle Power Technology Alliance
- PACOM/NORTHCOM SPIDERS JCTD
- State of Hawaii
- University of Hawaii-HNEI
- Hawaii Tri-Service Military Installations

- Supports the increase in renewable energy
- Military as an early adopter
- Develop a competitive & sustaining industry
- **Army Hydrogen based Vehicles & Refueling**
- **Army Microgrid 1-**
 - 250kW sufficient to power a building
- **Army Microgrid 2-**
 - 450kW capable of powering 500-Soldier/Forward Operating Base

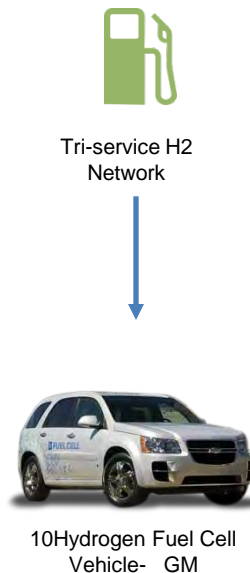
Hydrogen Vehicles with Internal Combustion Engines(H2ICE)



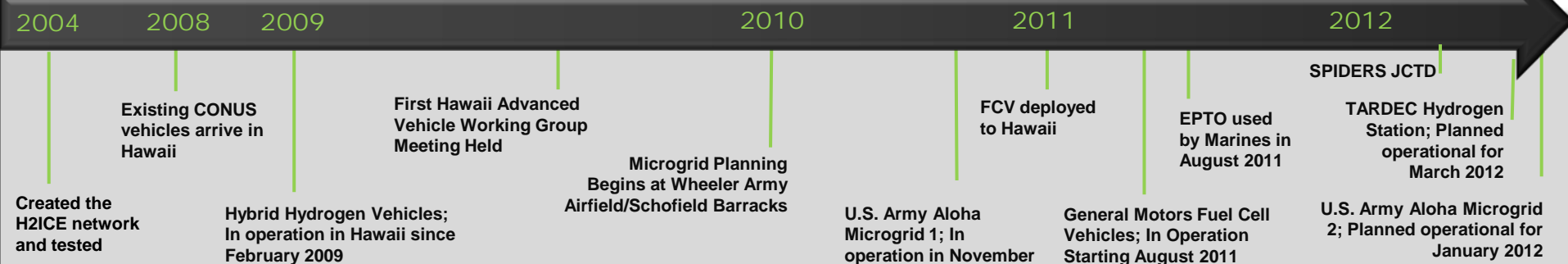
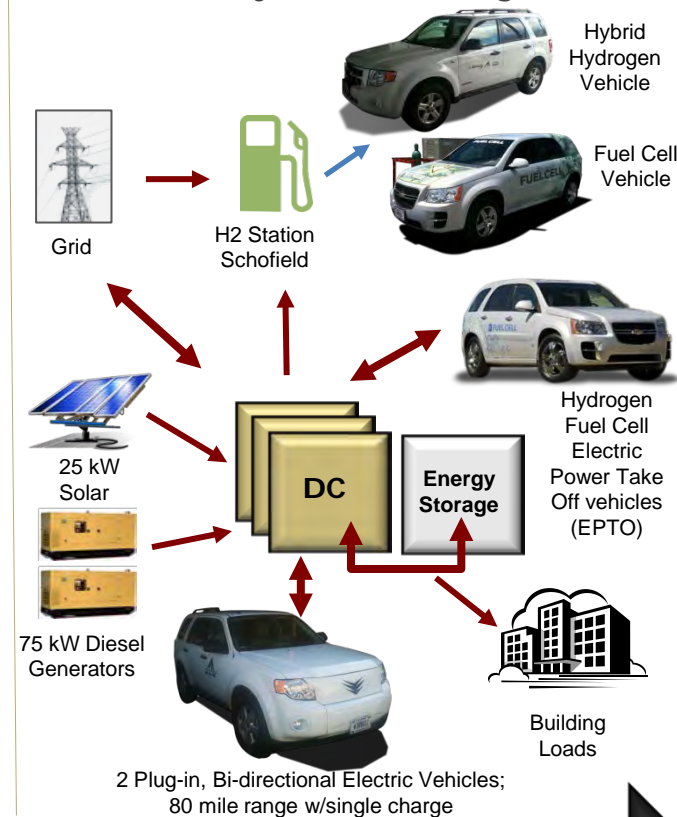
U.S. Army Aloha Microgrid 1



Hydrogen Fuel Cell Vehicles



U.S. Army Aloha Microgrid 2



Unclassified FOUO



Lead. Innovate. Integrate. Deliver.

Vehicle to Grid



Demo bi-directional power for grid services (HI)



Interface standards
Physical, communication, cyber-
security
(SPIDERS – Ft. Carson)



Export power system development and demonstration



Microgrids



Modular mobile microgrid product
development



Enduring microgrid product
development and demonstration
(NetZero JCTD - Ft Irwin, others)



Tactical load control product
development



Integrated microgrid testbed
demonstration (HI)

Hydrogen fuelled
propulsion



Hydrogen ICE fleet
demonstration (HI)



Demonstration of fuel cells in non-tactical fleet (past Ft. Belvoir,
current HI)



Fuel cell propulsion concept
development



Hydrogen Infrastructure



Infrastructure component development



Hydrogen refuelling demonstration
(past Selfridge, MI; future HI)



Power Generation



Diesel
Engines

Transmissions



Rotary Engines



Traction Motors



JP-8
Fuel Cells

Integrated Starter Generators



Turbine Engines



Alternators



Drivelines

Energy Storage



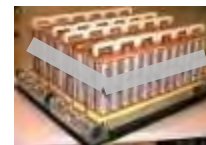
Li-Ion / Ultracap Hybrid Energy
Storage



Capacitors



Advanced Batteries



Thermal Mgmt & Power Distribution



Radiators



Microgrids



Power Controllers for
Power Management



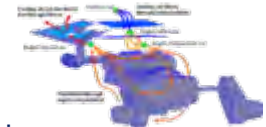
Heat Recovery



Power Converters /Inverters



Advanced Electronics
Cooling



Thermal
Architecture

Materials



Lightweight
Materials



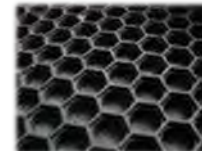
Thermal Interface Materials



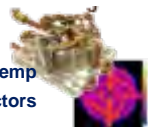
Wide Band Gap Materials (SiC)



High Temperature SiC
Modules



Lightweight Structures



High Temp
Inductors

Fuels & Lubricants



Qualifications &
Specifications



Biomass Energy
(Renewable)



Conversion
Process



Single Fuel

Vehicle Inputs



Plug-in Hybrid Electric
Vehicles (PHEV)

Renewable Inputs



Mobile Encampment Waste to
Electrical Power (MEWEPs)

Generator Inputs



Solar



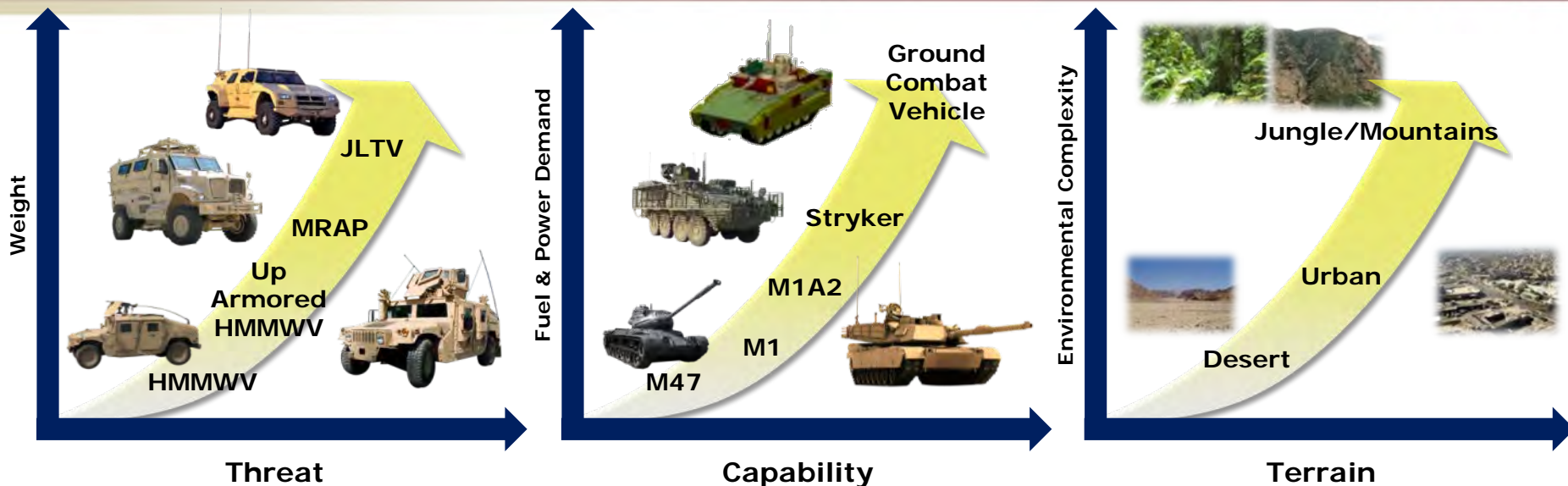
Tactical Quiet
Generator (TQG)



Electric Power Control and
Conditioning (EPCC)



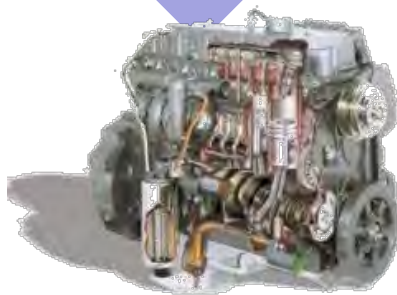
Supply – Infrastructure - Demand



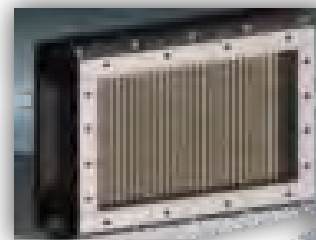
Increasing Demands and Operational Flexibility
Require Strategic Investments in Key Areas



Energy Storage



**Power Generation
& Control**



Thermal Management



Track & Suspension

